National Aeronautics and Space Administration

Results of Additional Studies

NASA is committed to communicating with the public about the Groundwater Cleanup Project at the Jet Propulsion Laboratory (JPL). This information sheet describes the results of several integrated studies we recently completed.

NASA is making significant progress with cleanup efforts at the Jet Propulsion Laboratory (JPL). We recently completed soil cleanup, and we are in the process of expanding the capacity of our source area (onsite) groundwater treatment facility. We continue to fund the treatment system for two Lincoln Avenue Water Company drinking water wells and to work with the City of Pasadena to fund its construction and operation of a new groundwater treatment facility in northern Pasadena. Cleanup efforts also include completing an in-depth site investigation required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Beginning in 1992, NASA conducted several investigations to determine the type and extent of chemicals originating from historic waste practices at JPL.

There have been detections of perchlorate at various wells located in the Raymond Basin aquifer, including wells near the Sunset Reservoir. These findings prompted NASA to conduct further study in the area to:

Understand the downgradient (southern) extent of chemicals that originate from JPL, and

Determine if the occurrence of perchlorate in the Sunset Reservoir area was associated with migration from the JPL facility.

Four analytical tools were used: Groundwater Modeling, Groundwater Geochemistry, Groundwater Chemical Data and Perchlorate Isotope Analysis. When evaluated together, these studies provide an understanding of the complexities of underground conditions and the existence of perchlorate in groundwater in the Raymond Basin.

NASA has collected data from monitoring wells (referred to here as MW) since the mid-1990s. In 2004, two new multi-port wells were installed and added to NASA's quarterly groundwater monitoring program to help understand the extent of chemicals from JPL. Multi-port wells allow sampling of groundwater from up to five different depths. The new wells, MW-25 and MW-26, are located between what was formerly the southernmost NASA monitoring well (MW-20), and the Sunset Reservoir area.

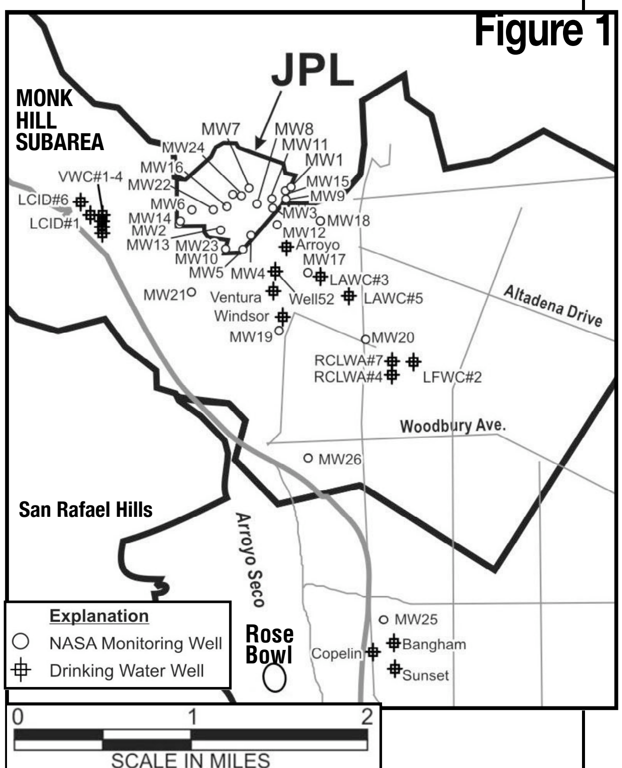


Figure 1 shows the locations of monitoring wells installed as part of NASA's CERCLA program. Also shown are the locations of several water supply production wells in the Monk Hill Subarea of the Raymond Basin and wells near the Sunset Reservoir area.

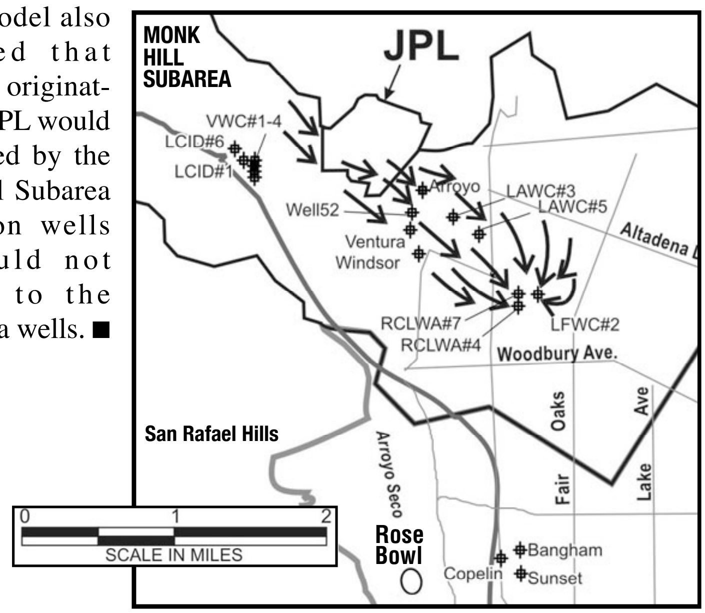
NASA conducted additional studies according to the workplan approved by the U.S. Environmental Protection Agency, California Department of Toxic Substances Control, and the Regional Water Quality Control Board. The Department of Health Services and the City of Pasadena provided input on the plan. ■

Groundwater Modeling

Computer modeling was used to estimate groundwater flow direction and velocity and to understand how chemicals from JPL move over time. Part of this analysis included asking how water production (drinking water) wells affect groundwater movement while the wells are operating and during periods when they are not. When a production well is extracting water during operation, the pumping action will draw groundwater flow toward the well, creating an area called a capture zone.

Particle tracking simulations were performed using a model that NASA developed initially to evaluate groundwater treatment alternatives and groundwater flow in the Monk Hill Subarea. In this study, normal seasonal variations were accounted for and average water extraction rates from 1960 to 2000 were used. Particle tracking works by releasing a computer-generated (imaginary) particle at a specific location and following its path in the aquifer. Modeling showed that particles originating from the JPL facility would be captured by wells in the Monk Hill Subarea, primarily by Arroyo Well, Well 52, and the Lincoln Avenue Water Company (LAWC) Well 3. [See Figure 2] In addition, there did not appear to be any times since the 1940s when Monk Hill Subarea production wells experienced widespread or complete shutdown. Any chemicals that escaped containment while some wells were closed likely would have been captured by other production wells in the Monk Hill Subarea that were in operation during that time.

Computer models are only representative of actual conditions. As with any scientific study, the ability to replicate an experiment and get similar results increases confidence in the methods used. NASA also evaluated a groundwater flow model that was developed independently by the Raymond Basin Management Board (RBMB) to evaluate potential changes to groundwater levels and movement throughout the Raymond Basin, including the Monk Hill Subarea. Results from the RBMB model also indicated that chemicals originating from JPL would be captured by the Monk Hill Subarea production wells and would not migrate to the Sunset area wells. ■



Computer modeling shows that production well pumping action draws groundwater flow toward the well creating an area called a capture zone. Chemicals originating from JPL would be captured by wells in the Monk Hill Subarea and would not migrate to the Sunset area wells.

Groundwater Geochemistry

Groundwater chemistry data are used primarily to evaluate drinking water quality. Because the groundwater in the Raymond Basin has been used as a source of drinking water for more than 100 years, chemical analyses data are available from production wells dating back to the early 1900s.

Historical records show that connection to the Metropolitan Water District (MWD) aqueduct tunnel at Sunset Reservoir was completed in 1941, and delivery of Colorado River water began in June of that year. Geochemistry data show a significant change in the concentration of various dissolved chemicals in the Raymond Basin associated with imported water.

More than 1 million acre-feet of Colorado River water have been imported by the Metropolitan Water District (MWD) to the Raymond Basin since the 1940s to supplement local drinking water supplies. More than 30% of the water used in the Raymond Basin between 1952 and 2002 was from the Colorado River. An estimated 25% of imported water has made its way to the Raymond Basin aquifer via irrigation, leaking pipes, unsewered areas, and direct injection.

To understand the impact of imported Colorado River water on groundwater, we looked specifically at the ion concentration data. (An ion is an atom or group of atoms that has a positive or negative charge as a result of having lost or gained one or more electrons.) These data were collected both from local drinking water wells and NASA's groundwater monitoring program. Plotting this data (called Piper diagrams) assists in visualizing the geochemical variations in the water. These analyses confirmed that three distinct water types are found in the Raymond Basin aquifer.

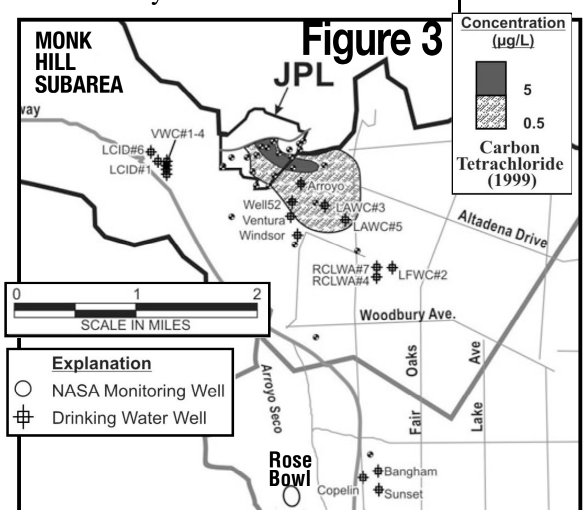
Type 1 water is characterized by its trace amounts of dissolved calcium and bicarbonate ions. It originates as rainwater runoff from the San Gabriel Mountains and filters through the earth into the Raymond Basin. Type 1 water is native groundwater found at shallower depths.

Type 2 water is characterized by its trace amounts of dissolved sodium and bicarbonate ions and is found in deeper portions of the aquifer. Type 2 water is native groundwater that has been in contact with minerals in the subsurface.

Type 3 water is created by mixing of imported Colorado River water with native water. This results in water becoming relatively enriched in sulfate and chloride ions. Type 3 water consistently has higher levels of total dissolved solids (TDS) than either of the other two water types. Geochemical data confirm that Type 3 water did not exist in the Raymond Basin prior to the introduction of Colorado River water in the 1940s and 1950s.

The influence of imported water on the Raymond Basin is important because Colorado River water is known to contain perchlorate and sulfate. Although perchlorate data are not available prior to 1997, we do have sulfate data, which serves as a tracer for the influence of imported water. Chemically, perchlorate acts like sulfate in groundwater. Sulfate is a very stable compound and does not biodegrade under the conditions found in the Raymond Basin. Elevated sulfate levels in groundwater show the impact that Colorado River water has had since being introduced to the area in the 1940s. It appears that the change in water quality is a result of imported Colorado River water mixing with native groundwater – shifting it from Type 1 (native, shallow) to Type 3 (Colorado River water introduced into the aquifer).

Geochemistry data show how the Raymond Basin, including the Sunset area wells has been impacted by Colorado River water. These data alone do not show whether there are additional sources or how much of the perchlorate in the Sunset area wells is from the Colorado River water. ■



Carbon tetrachloride is considered a tracer for chemicals originating from JPL, and has not been detected beyond approximately one mile downgradient from JPL.

Groundwater Chemical Data

The third analytical tool used by NASA was evaluating groundwater chemical data. Groundwater samples are regularly collected from production wells, which supply public drinking water. These samples are analyzed for chemicals specified by federal and state law and regulations. In addition, NASA has collected thousands of groundwater samples on a quarterly basis for more than a decade from more than 20 monitoring wells, both on- and off-facility at JPL. These samples are routinely analyzed for chemicals historically used at the facility including volatile organic compounds (VOCs), certain metals and perchlorate. These data were used to understand the extent of chemicals originating from JPL.

Carbon tetrachloride is the primary VOC that is associated with past operations at the facility and the JPL cleanup. The only known source of carbon tetrachloride in the Monk Hill Subarea groundwater is from JPL. Carbon tetrachloride, therefore, can be considered a tracer for chemicals originating from JPL. In the wells where carbon tetrachloride is found, perchlorate originating from JPL is also found. A review of more than 10 years of monitoring data shows that carbon tetrachloride has not been detected beyond approximately one mile downgradient from JPL. [See Figure 3] NASA recognizes that, due to its chemical properties, perchlorate could travel faster than carbon tetrachloride in the absence of groundwater pumping. Still, no carbon tetrachloride has been detected outside of the Monk Hill Subarea. This correlates well with our understanding of production well capture zones and provides additional evidence that perchlorate originating from JPL is contained in the Monk Hill Subarea.

Another interesting finding associated with the groundwater chemical data is the elevated levels of perchlorate in MW-21, detected in the late 1990s. [See Figure 1 for well locations] Chemical data from MW-21 detects no carbon tetrachloride. In addition, groundwater modeling shows that MW-21 is in the flowpath between the upgradient area of La Cañada and the capture zone of the downgradient Sunset area wells. The Monk Hill Subarea capture zone is separate. These results provide evidence that elevated levels of perchlorate in MW-21 are from a source of perchlorate not associated with JPL. ■

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Perchlorate Isotope Analysis

Perchlorate in the environment today is widespread. Sources of perchlorate include road flares, fireworks, blasting operations, and other commercial and military products, as well as rocket propellant. A well documented naturally occurring perchlorate is found in nitrate salt deposits of the Atacama Desert in Chile. These deposits have been exported extensively since about 1870 for use as agricultural fertilizer. According to the California Department of Agriculture, more than 477,000 metric tons of Chilean nitrate were used in the state to fertilize crops between 1923 and 1998. Other natural perchlorate has been reported in samples of rain and snow. This naturally occurring perchlorate, as well as the different man-made sources of perchlorate, can be measured and be potentially differentiated by their isotopic "fingerprint".

NASA collected groundwater samples for perchlorate isotope analysis from 13 locations including three of the five Sunset area wells (Sunset, Bangham, Garfield).

Dr. Neil Sturchio, a specialist in the field of isotopic analysis from the independent laboratory of the University of Illinois at Chicago, conducted the analysis for NASA. Specific isotopes of chlorine and oxygen, in the man-made type of perchlorate historically used at the site, were measured and evaluated. These analyses were able to (1) distinguish the JPL perchlorate as having an isotopic fingerprint distinct from other sources in the Raymond Basin and (2) show that the perchlorate found at Sunset wells appears to be from at least two different sources: man-made (e.g., found in imported Colorado River water, fireworks, flares, etc.) and naturally-occurring (e.g., imported in large quantities of fertilizer from Chile). ■

Summary of Results

Groundwater Modeling

Modeling developed by NASA and independently by the RBMB indicate that dissolved chemicals from JPL would be contained by production wells in the Monk Hill Subarea and not migrate to the Sunset area wells.

Groundwater Geochemistry

Imported Colorado River water has changed the geochemistry of groundwater in the Raymond Basin. Imported Colorado River water also is known to contain perchlorate.

Groundwater Chemical Data

Carbon tetrachloride is considered a tracer for chemicals originating from JPL and has not been detected beyond approximately one mile downgradient from JPL, which is consistent with modeling results.

Perchlorate Isotope Data

Perchlorate originating from JPL has a fingerprint that is distinct from the fingerprint of perchlorate present in the Sunset area wells.

Results

The investigation employed the use of four different analytic tools. Taken together, the results of the groundwater modeling, groundwater chemistry, groundwater chemical data and groundwater monitoring, and isotopic analysis, lead to the conclusion that (1) NASA has determined that the chemicals from the JPL facility are captured within the Monk Hill Subarea, and, (2) the perchlorate detected at the Sunset area wells is of a different origin than that used at and originating from JPL.

For More Information

More information about the NASA Groundwater Cleanup Project at JPL is available on our **Web site** http://jplwater.nasa.gov and at the **NASA Information Repositories** located in the Pasadena Central Library, La Cañada Flintridge Public Library or the Altadena Public Library.

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Four Study Methods Described

Providing the public with updates on our progress is an important part of NASA's Groundwater Cleanup Project at the Jet Propulsion Laboratory. This information sheet describes tools NASA used in recent studies. The findings are explained in a separate information sheet entitled, "Results of Additional Studies".

NASA is making significant progress on the Groundwater Cleanup Project at the Jet Propulsion Laboratory (JPL). Our efforts include investigating the site according to the framework required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The investigation phase of CERCLA involves in-depth sampling and other analyses to identify the types of chemicals that might be present at a site and how such chemicals might be moving in groundwater deep beneath the surface. A thorough understanding of these conditions enables us to determine the needs for cleanup.

Key to this investigation is the data we collect using conventional and multi-port groundwater monitoring wells. Conventional wells (single screen) and multi-port wells (2 - 5 screens at different depths) give us information from various specific locations at a cleanup site. Installation of a series of wells in and around the cleanup site provides a wealth of data for characterizing the extent of chemicals traveling in a specific area underground. NASA has been collecting groundwater samples on a quarterly basis from monitoring wells, both on- and off-site, for more than a decade. These data help NASA characterize the extent of perchlorate and other chemicals associated with historic operations at the JPL facility in the 1940s and 1950s.

Since completing an initial investigation in 1999, NASA has recommended and implemented several cleanup activities onsite and beyond the JPL fenceline. Even with all the detailed information collected from that investigation, several questions emerged in the late 1990s regarding the widespread occurrence of perchlorate (since analysis for it began in 1997) in the Raymond Basin. These questions prompted NASA to supplement the initial investigation results and conduct further study in the area.

objectives

The primary objectives of this supplemental study are twofold:

Understand the downgradient (southern) extent of chemicals that originate from JPL, and

Determine if the occurrence of perchlorate in the Sunset Reservoir area was associated with migration from the JPL facility.

Four Study Methods

The methods NASA has used in this investigation include: 1 Groundwater Modeling, 2 Groundwater Geochemistry, 3 Groundwater Chemical Data, and 4 Perchlorate Isotope Analysis. Each of these tools provides valuable information. Rather than relying on any one method in and of itself, we have used the four tools in an integrated manner to investigate the complexities of underground conditions in the Raymond Basin.

1 Groundwater Modeling

Computer modeling has a variety of applications in the field of environmental science and is commonly used to investigate groundwater movement such as the direction and rate at which groundwater travels. Computer modeling also allows us to ask, "What would happen if…?" Ranging from relatively simple mathematical equations to complex multi-layer computer programs, groundwater models can create a virtual environment where "what ifs" can be explored. As one tool in a comprehensive investigation, groundwater models can help us estimate possible outcomes on groundwater levels and flow paths from human activities such as development, irrigation and water production wells. Models are particularly helpful in studying the direction and velocity of groundwater flow, predicting how chemicals move in groundwater, and evaluating the potential effectiveness of remediation alternatives. Because models simulate and cannot exactly duplicate all the conditions in a real environment, modeling results are more robust when supported by other data. Properly characterizing a site's geology and hydrology is a key element in building a better groundwater model. The more data describing the site-specific conditions we have to input into the model, the closer it will approximate the real physical setting (called model calibration) and provide an accurate prediction of groundwater flow and direction.

For the initial investigation, NASA developed a computer model using information gathered from historical records and actual site measurements to estimate groundwater flow paths (direction) from JPL. We have used this model to perform particle tracking. The computer-generated particles simulate how chemicals found at the site might move over time. Part of this analysis included asking what effects do the existing water production wells have - while operating and during periods when they are not - on groundwater flow. When a water production well is operating, the pumping action will draw groundwater flow toward the well. This area is called the "capture zone" of that well. We have looked at whether production wells in the Monk Hill Subarea – one of three subareas that together make up the Raymond Basin aquifer – disrupt the natural flow path of groundwater from JPL and whether perchlorate migrating in that groundwater is being contained within the capture zones of those wells.

A groundwater model was developed independently by the Raymond Basin Management Board (RBMB). The RBMB used the model to evaluate potential changes in groundwater levels and movement throughout the Raymond Basin, including the Monk Hill Subarea. NASA has examined the results of that groundwater model as part of our study to verify our model results and increase our knowledge of groundwater conditions. ■

2 Groundwater Geochemistry

Every drop of groundwater tells a story. Groundwater geochemistry is the science that looks at how that story unfolds. It is one tool NASA has used to identify the distinct chemical makeup of groundwater that in turn can tell us where the water came from, when it entered the aquifer, and whether factors have been at work on it underground, potentially changing its makeup. Some of these factors include the breakdown (dissolution) of naturally occurring minerals and other interactions with soils, mixing of different water sources, and human activities.

Groundwater samples are collected from monitoring wells and from municipal drinking water production wells in the Monk Hill Subarea. Analysis of these samples in the initial investigation found three general types of groundwater to be present. These data have been used to understand the origin of each of the three types of groundwater and whether there are any connections with sources of perchlorate in the Raymond Basin.

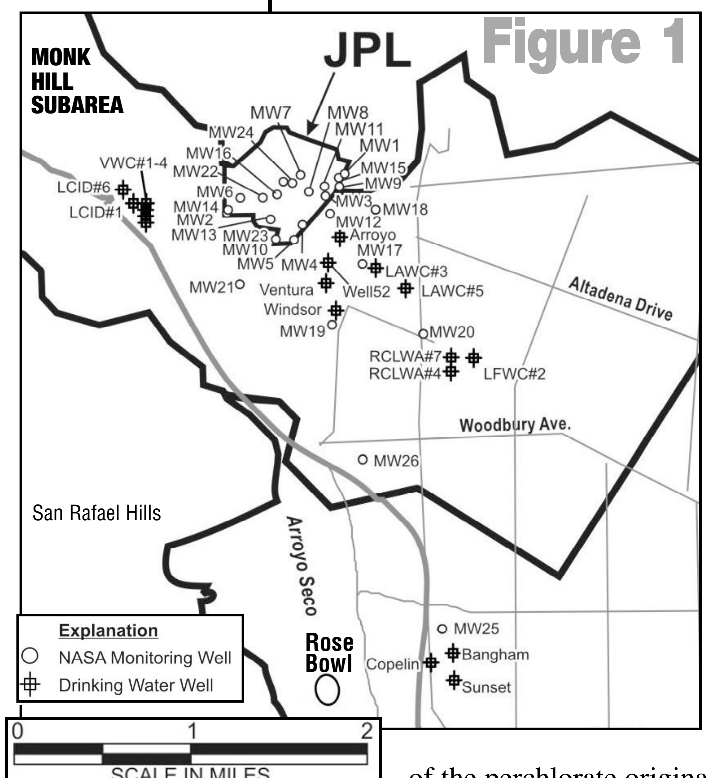
Different water sources have different groundwater geochemical fingerprints that can be identified by looking at the chemicals in the water. Calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, and nitrate are chemicals commonly found in water in significant quantities. These chemicals are naturally occurring, and some are from human activities. The groundwater in the Raymond Basin has been used as a source of drinking water for more than 100 years, and chemical data are available from production wells dating back to the early 1900s. (Federal and state regulations oversee and require water purveyors to provide safe drinking water to consumers.)

In addition to using specific chemicals to analyze and identify groundwater samples, other trace chemicals are used to track the origin of the groundwater. The radioactive isotope tritium, for example, proves to be an excellent tracer for identifying relatively young water. Tritium input to surface waters has occurred in a series of spikes following periods of atmospheric testing of nuclear devices that began in 1952 and reached a peak in 1963-64. Radioactive decay of tritium has a half-life of 12.43 years, and the decay product is helium. Measuring the concentrations of tritium and helium in groundwater can provide accurate information on the time since the groundwater was exposed to the atmosphere or when it was introduced into the aquifer. Having this information helps us to track the water to its origin. ■

3 Groundwater Chemical Data

Multi-port groundwater monitoring wells, which have screens at different and specific depths, allow us to draw groundwater and take samples from many levels below the surface. Installing a series of wells in strategic locations at a cleanup site and collecting and analyzing samples on a regular basis is a standard practice for tracking chemicals underground. Since completion of the initial investigation, perchlorate has been detected in wells near the City of Pasadena's Sunset Reservoir area. To gather additional information, NASA installed two new multi-port groundwater monitoring wells in 2004. The new wells, MW-25 and MW-26, are located between what was formerly the southernmost NASA monitoring well (MW-20), and the Sunset wells area. [See Figure 1]

As part of our CERCLA groundwater monitoring program, we routinely collect samples from all 25 monitoring wells on a quarterly basis and analyze these samples for volatile organic compounds (VOCs), perchlorate and other chemicals historically used at the facility. The presence or absence of perchlorate at a particular well location and at specific depths, as well as any changes in perchlorate levels found there during a period of time, are recorded. These data can help determine the extent to which a particular chemical has or has not moved over time. Groundwater monitoring data have shown that the presence of a particular VOC, carbon tetrachloride, in the Monk Hill Subarea groundwater is associated with the JPL facility. Carbon tetrachloride is, therefore, considered a tracer for chemicals originating from JPL. We have evaluated the connection between the occurrence of carbon tetrachloride and perchlorate to help us better understand the extent of the perchlorate originating from JPL. ■



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4 Perchlorate Isotope Analysis

An isotope is an alternate form of an element such as hydrogen or oxygen that has the usual number of protons but a nonstandard number of neutrons. This gives each isotope a different atomic weight, which can be measured in the laboratory using a technology called mass spectrometry. Natural isotopic variations can arise from a number of chemical and physical processes and can alter the isotopic composition, or fingerprint, of a chemical. This can happen, for example, when fluids are heated or cooled, and when they evaporate or condense; during mixing of two or more sources of fluid, and in the natural biological processes of organisms (metabolic activity). The isotopic fingerprint of certain chemicals can be distinguished based on (1) where it came from (geographical location) in the case of naturally occurring chemicals, and (2) what it was made from (source materials) in the case of man-made chemicals. For example, naturally occurring perchlorate found in the Atacama Desert in Chile has a unique isotopic fingerprint.

Isotopic analysis is a growing field of study that helps scientists understand the origin of certain chemicals by their distinct fingerprints. Stable isotopes of chlorine and oxygen can be used to identify natural versus man-made perchlorate and to distinguish one perchlorate source from another.

In our study, an independent laboratory at the University of Illinois at Chicago has performed isotopic analysis – looking at the stable isotopes of perchlorate (e.g., chlorine and oxygen) on groundwater samples collected from NASA's monitoring wells and water production wells in the Sunset Reservoir area.

Isotopic analysis is one tool NASA has used to understand the perchlorate fingerprint originating from the man-made sources historically used at JPL.

NASA is committed to communicating with the public about the results of these studies. ■

For More Information

More information about the
NASA Groundwater Cleanup Project
at JPL is available on our **Web site** http://jplwater.nasa.gov
and at the **NASA Information Repositories**
located in the Pasadena Central Library, La Cañada Flintridge Public Library or the Altadena Public Library.

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